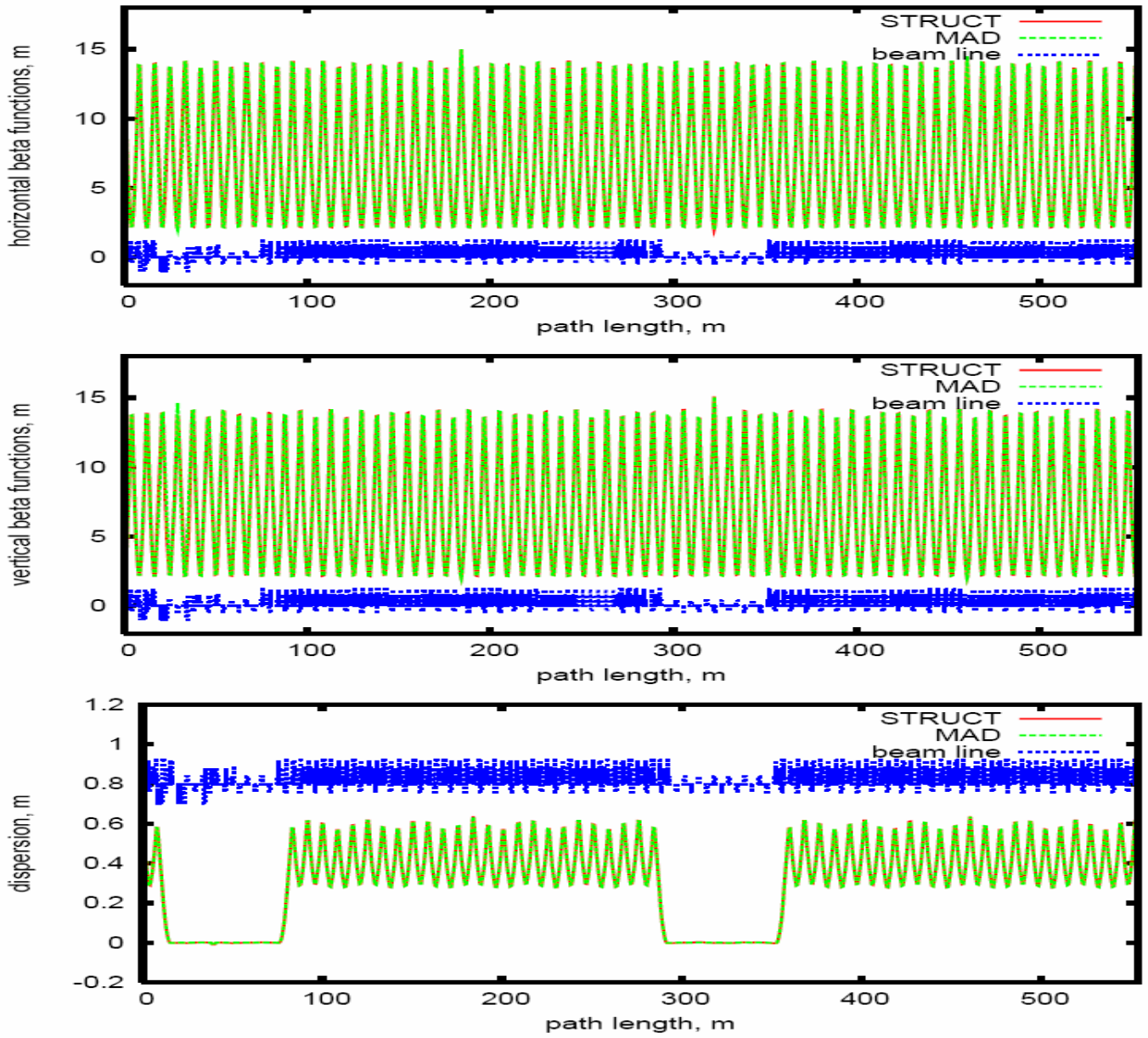
# Beam Injection and Collimation in the ACD Project X

A.I. Drozhdin, D.E.Johnson, N.V. Mokhov, I.L.Rakhno, L.G.Vorobiev

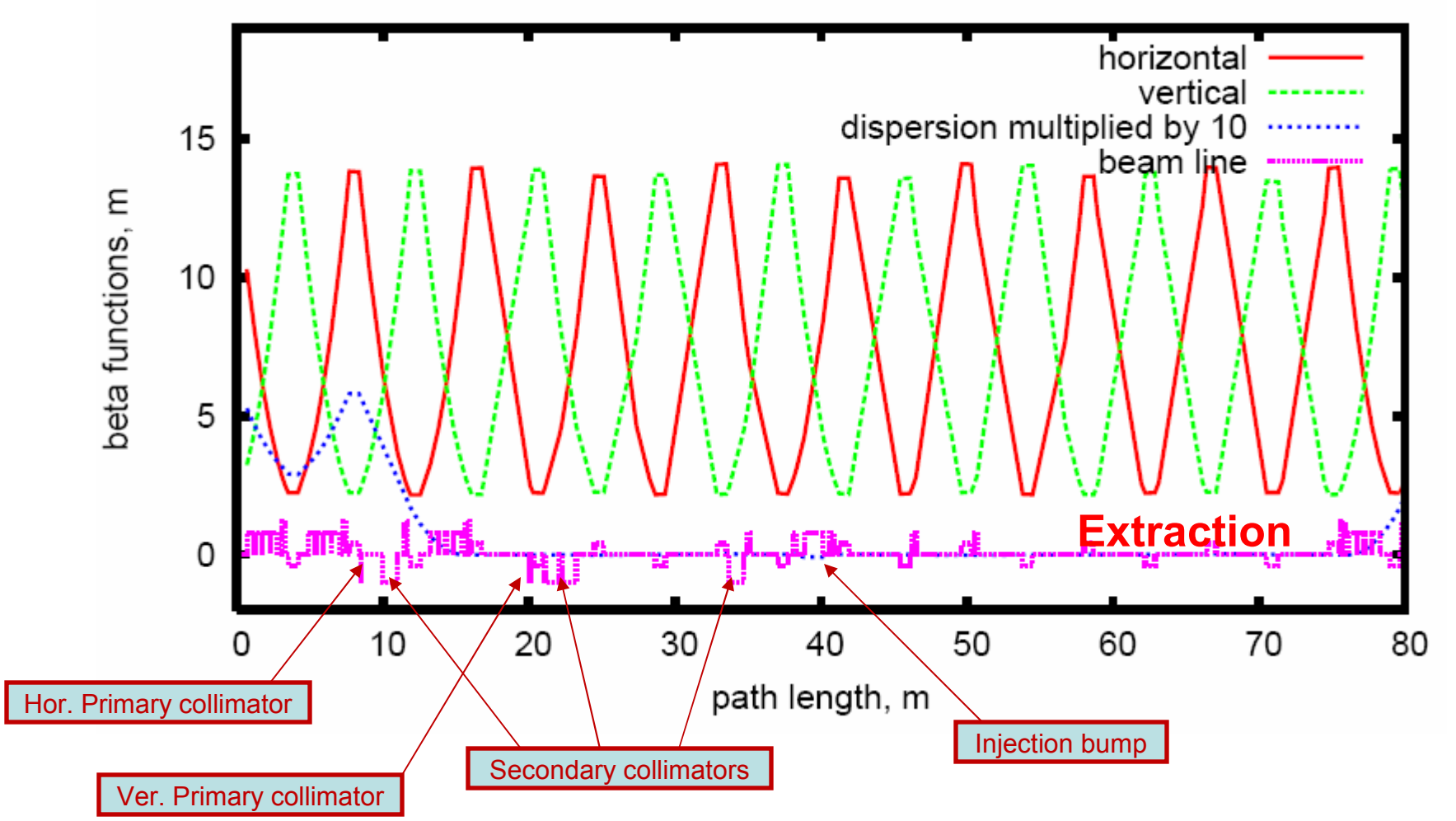
September, 2009

| parameter | value |
|---|---|
| Beam | |
| Proton momentum $P$ | 2.784437 $GeV/c$ |
| Equilibrium total energy | 2.938272 GeV |
| β-factor | 0.947644 |
| γ-factor | 3.13158 |
| 2-8 GeV Ring | |
| α | 0.00445 |
| Transition γ | 14.988 |
| Revolution time for Recycler Ring | 1.9473 $\mu$sec |
| Orbit length | 553.233m |
| Momentum spread, $dP/P$ at 3σ level | $1 \times 10^{-3}$ |
| RF frequency for 2 GeV central orbit | 50,326,093.0 Hz |
| Revolution frequency for Recycler Ring at 2 GeV | 513,532 Hz |
| Harmonic number | 98 |
| Painting Injection | |
| One painting cycle duration (train) | 4.284 msec (2200 turns) |
| Repetition rate of injection to Recycler Ring | 10 Hz (0.1 sec cycle) |
| Accumulated intensity in the Recycler Ring | $2.67 \times 10^{13} ppp$ |
| Power of the beam in the foil at injection | 85.44 kW |
| 95% normalized emittance of injected beam, $\varepsilon_{95\%}$ | 2.5 π $mm \cdot mrad$ |
| Geometric emittance of injected beam | |
| $\varepsilon_{1\sigma} = (2.5\ \pi/6) \times (0.938272/2.784437)$ | 0.1404 π $mm \cdot mrad$ |
| Momentum spread of injected beam, $dP/P$ at 3σ level | $8.4 \times 10^{-4}$ |
| normalized acceptance | 40 π $mm \cdot mrad$ |
| normalized emittance of the beam after painting, $\varepsilon_{total}$ | 25 π $mm \cdot mrad$ |
| Geometric emittance after painting | |
| $\varepsilon_{total} = 25\ \pi \times (0.938272/2.784437)$ | 8.4243 π $mm \cdot mrad$ |
| Momentum spread after painting, $dP/P$ at 3σ level | $1 \times 10^{-3}$ |
| Beta functions in the injection beam line at the foil, $\beta_x, \beta_y$ | 5.28 $m$, 2.21 $m$ |
| Injected beam half-size, $3\sigma_x = 3 \times sqrt(5.28 \times 0.1404)$ | 2.58 $mm$ |
| $3\sigma_y = 3 \times sqrt(2.21 \times 0.1404)$ | 1.67 $mm$ |
| Beta functions in the Recycler at the foil, $\beta_x$ | 9.38 $m$ |
| $\beta_y$ | 3.73 $m$ |
| Circulating beam half-size after painting, $3\sigma_x = sqrt(9.38 \times 8.4243)$ | 8.98 $mm$ |
| $3\sigma_y = sqrt(3.73 \times 8.4243)$ | 5.61 $mm$ |
| Longitudinal "slippage" of injected particles during one turn | $\delta\phi_{RF}$=0.6493 radian |
| 6.457883=325MH/50.326093MH | |
| $\delta\phi_{RF} = 2\pi \times 98 \times 0.457883/6.457883 = 43.658649 rad = -0.323648$ radian | |
| 0.972948rad=6.283185/6.457883 - distance between bunches | |
| -0.323648rad is equivalent to -0.323648+0.972948=0.6493rad | |

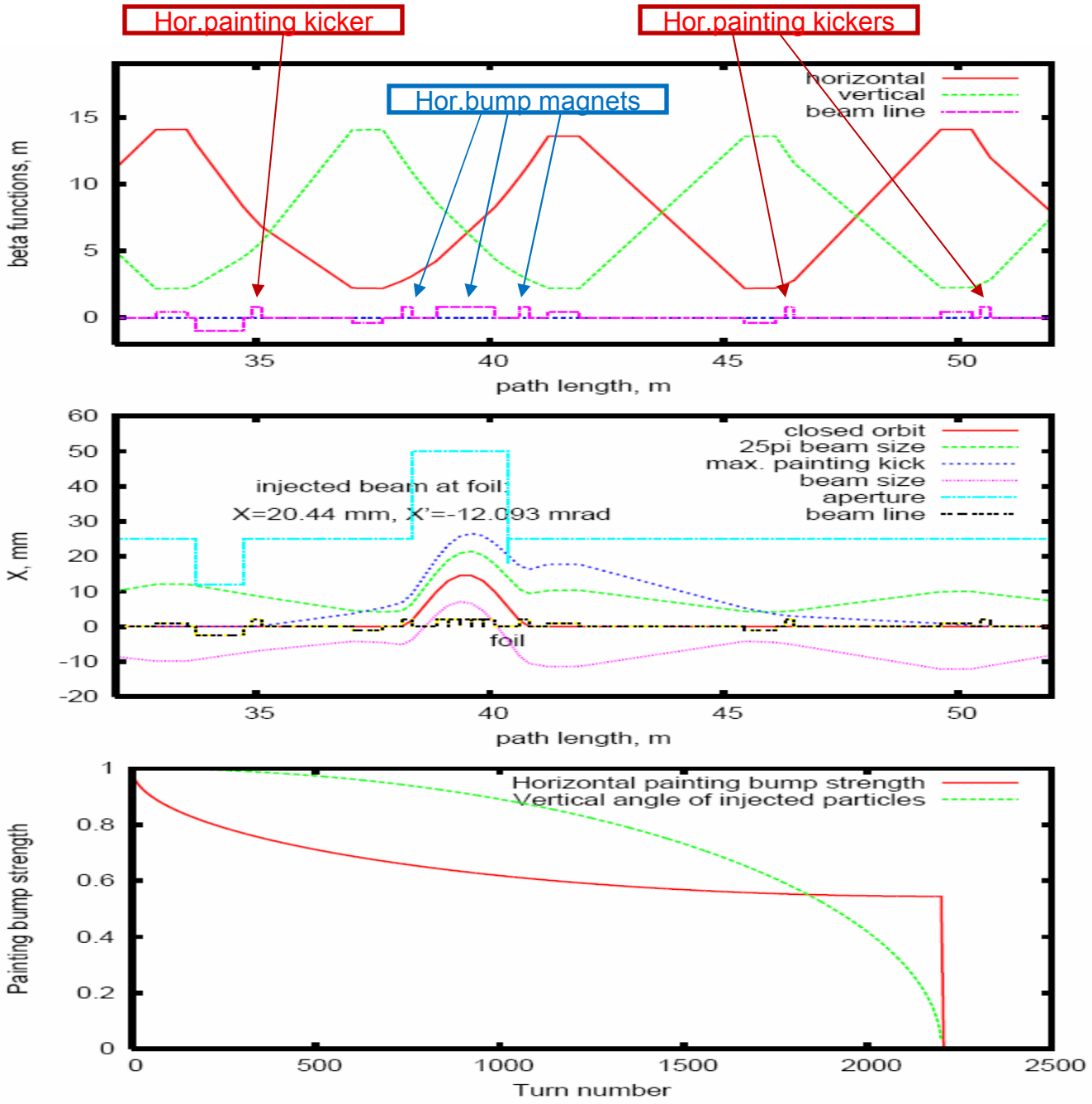
**Beam parameters at painting injection calculations.**



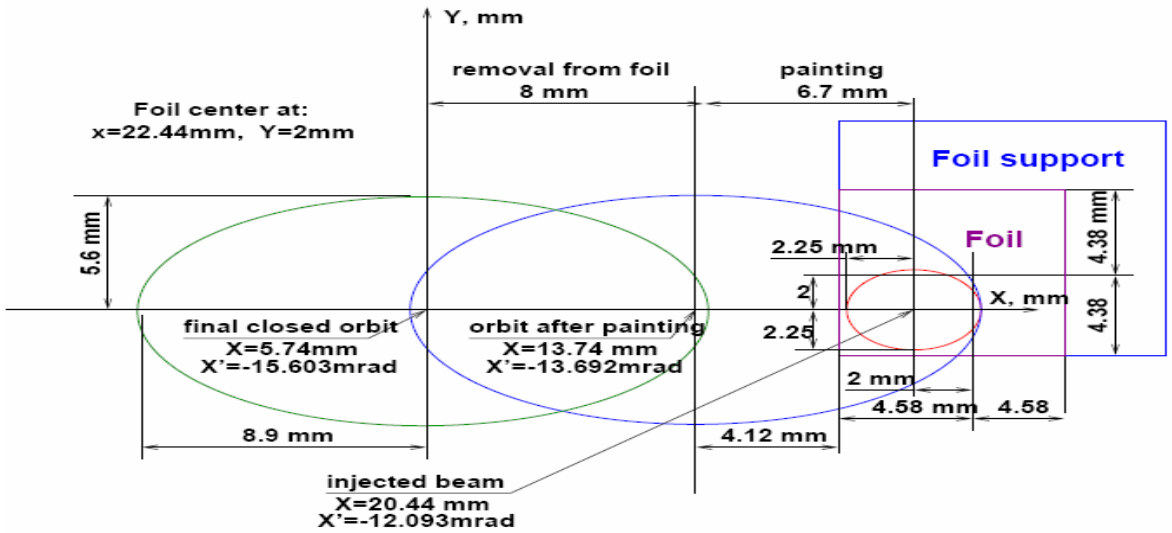

**Beta function and dispersion calculated by STRUCT and MAD at injection.**

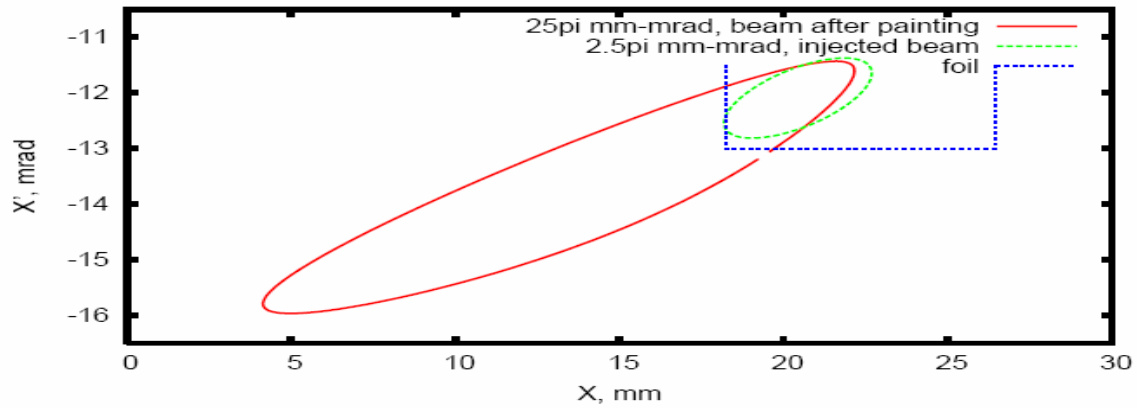


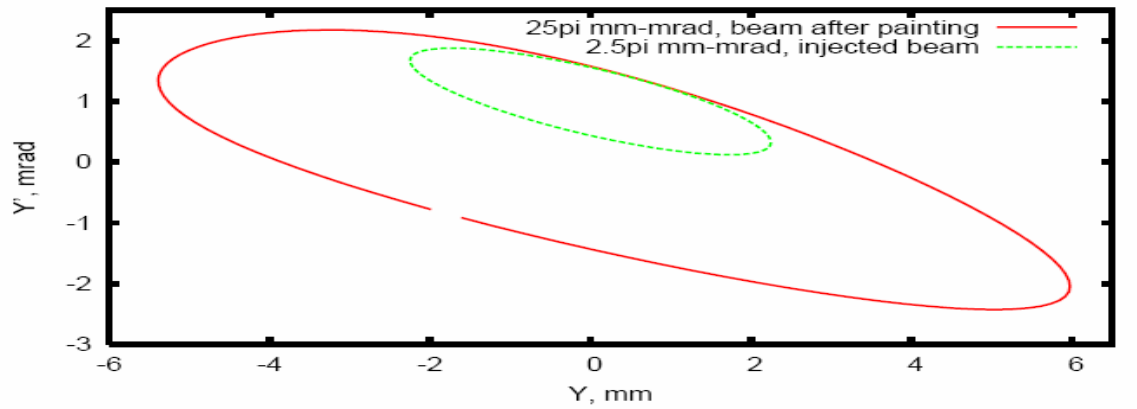

**Beta function and dispersion in the straight section at injection.**



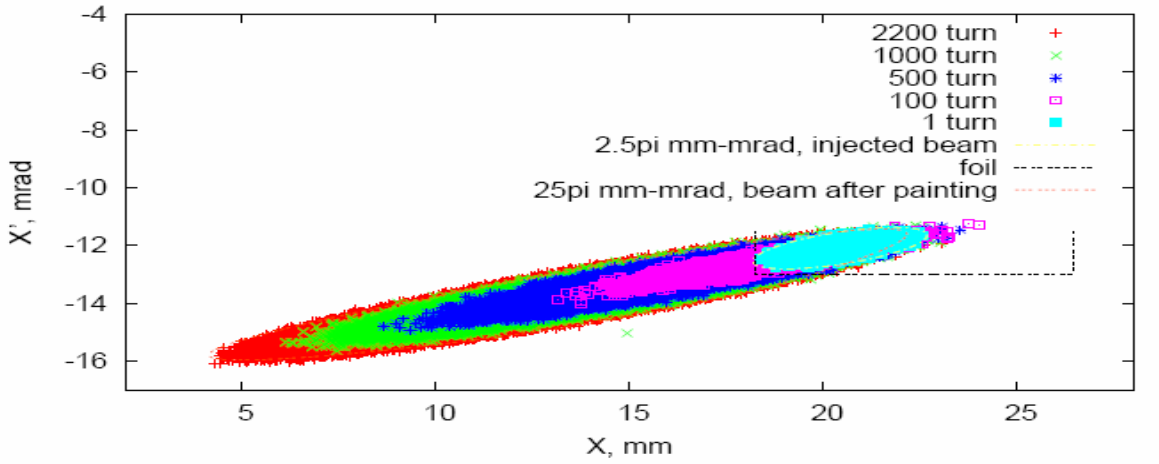

**Beta functions (top), beam orbit (middle) in the injection section, and painting bump strength (bottom) with KEK type waveform.**

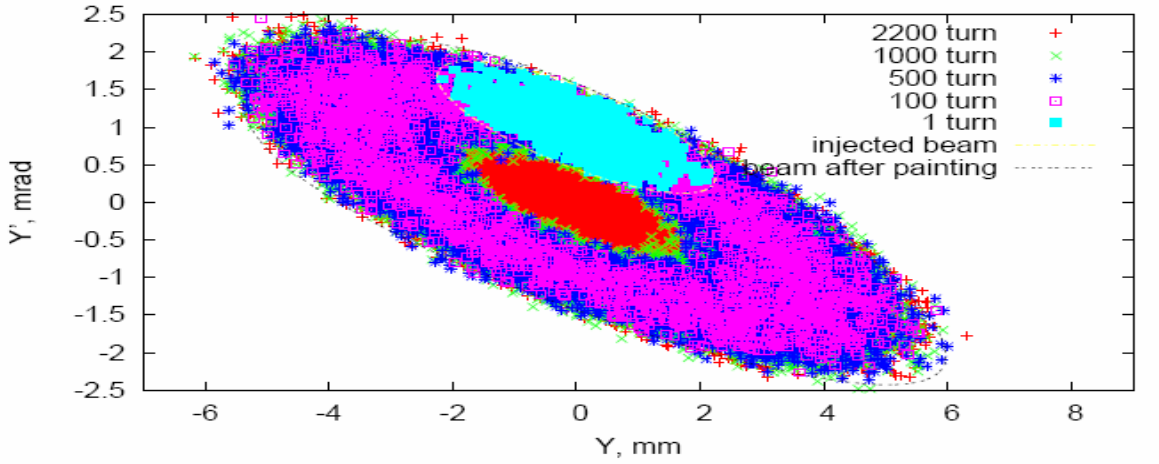


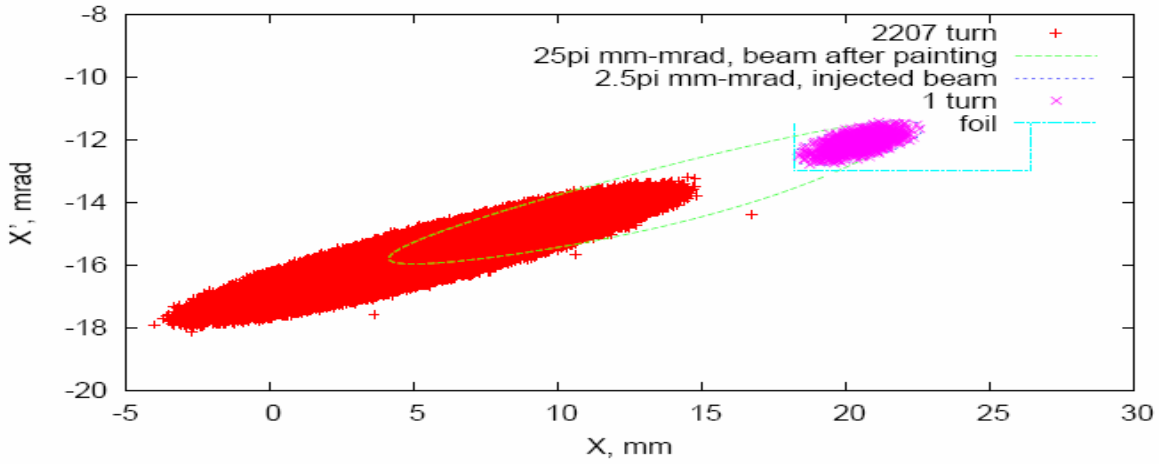



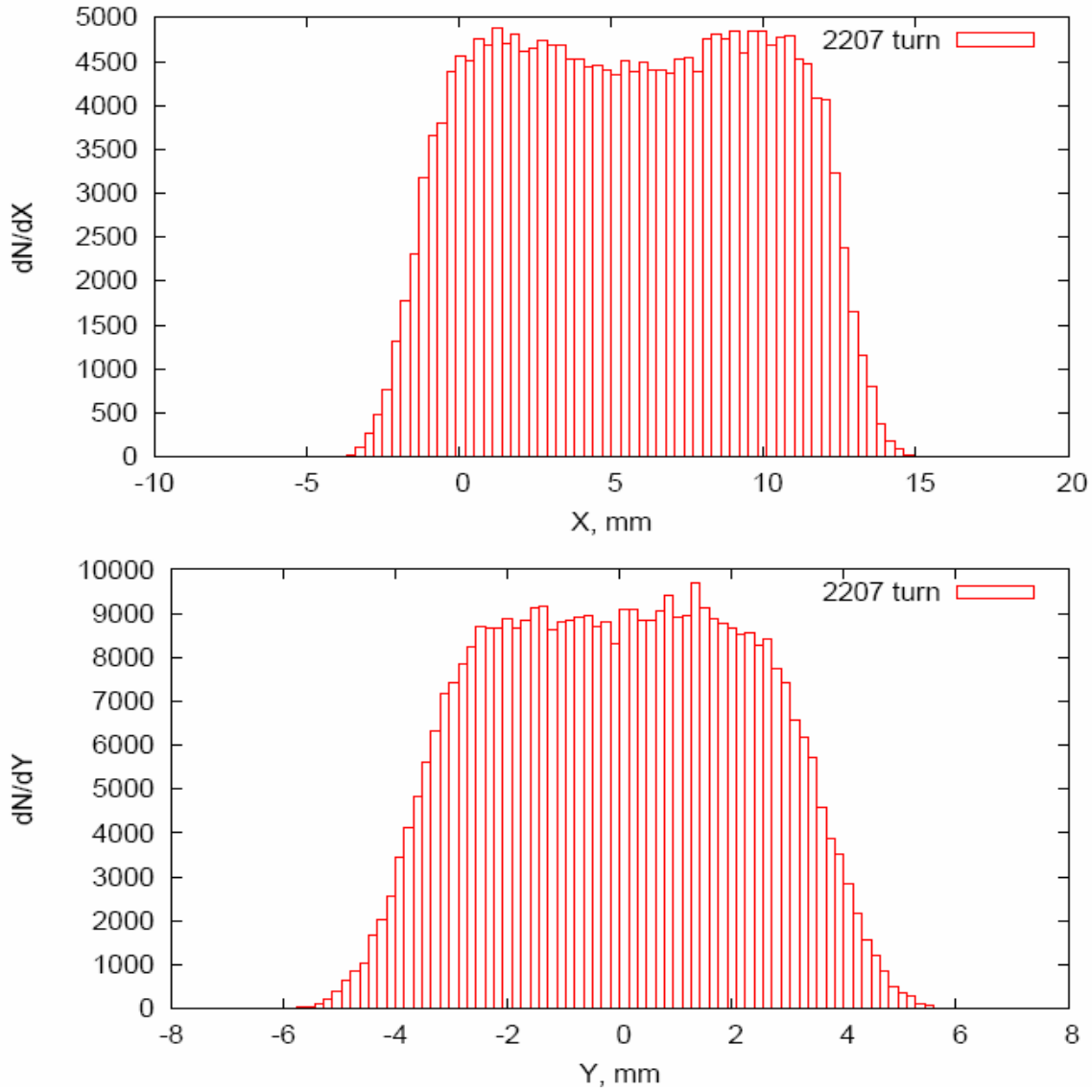

**Beam position at stripping foil at painting injection with KEK type waveform.**



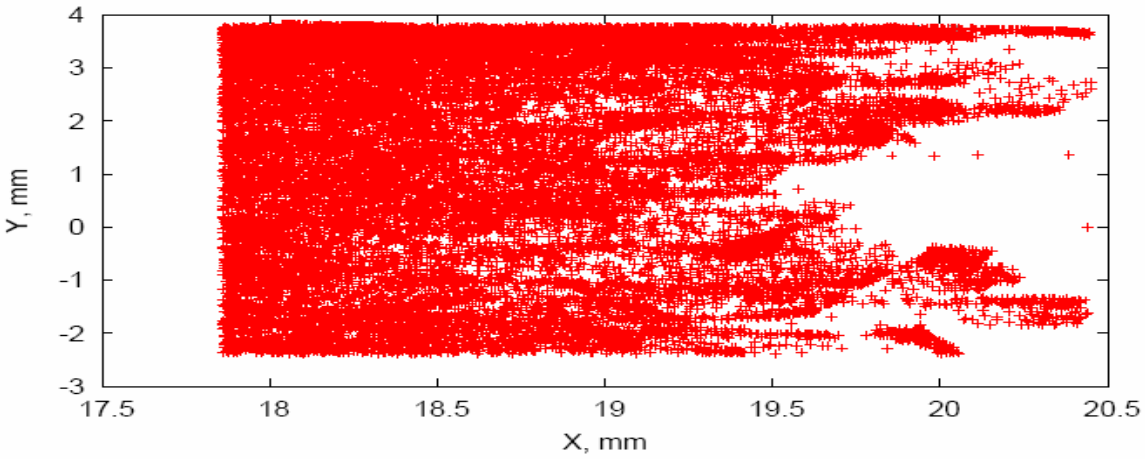



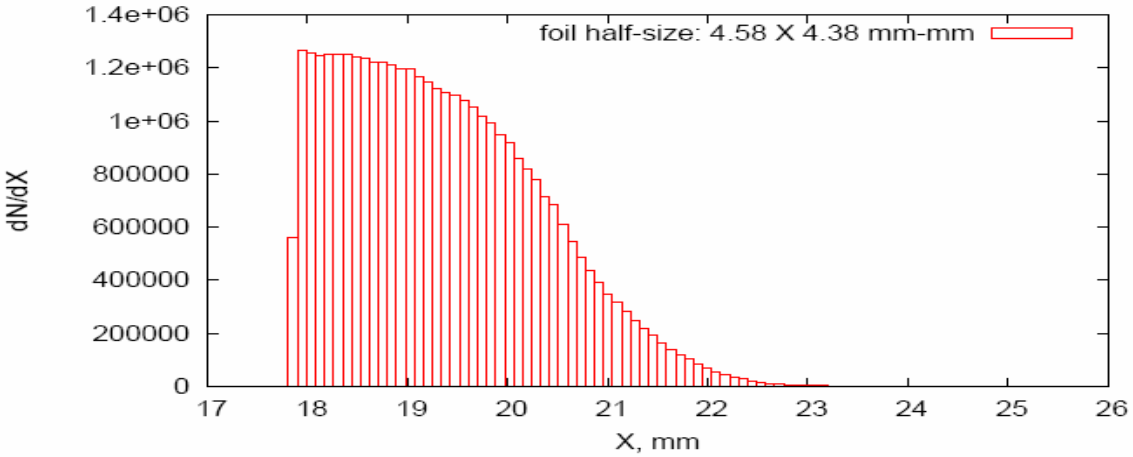



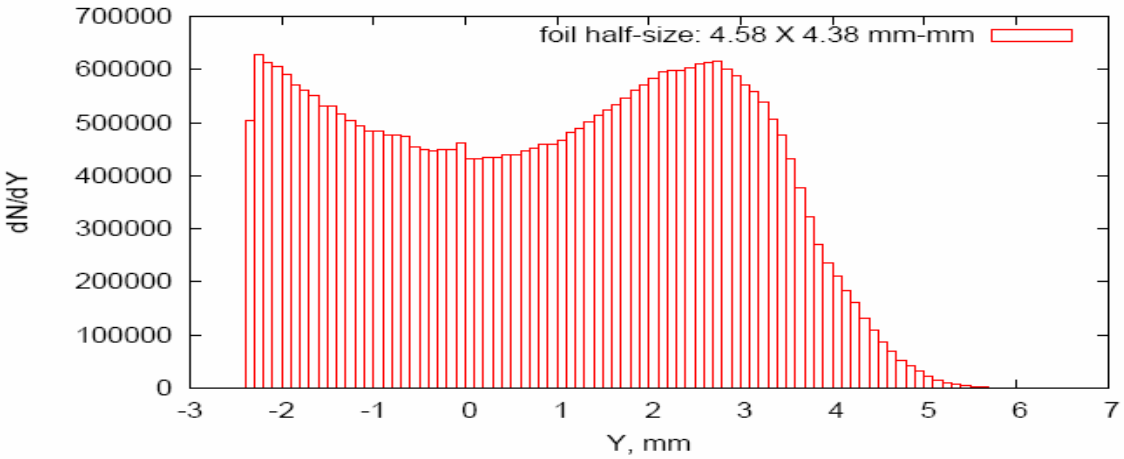

**Horizontal (top) and vertical (middle) phase plane of circulating beam at turns 1, 100, 500, 1000 and 2200 of injection with KEK type waveform. Foil half-size is 4.58 X 4.38 mm. Injected beam is taken at 3 σ level: Ax=2.25mm, Ay=2.25mm. Horizontal plane after beam removal from the foil (bottom). Average number of each particle interaction with foil is 139. Statistics is 30 particles injected at every turn.**



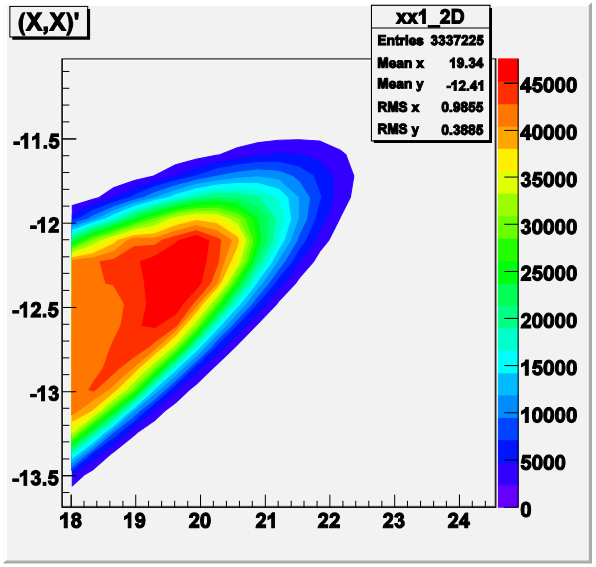

**Horizontal (top) and vertical (bottom) particle distributions after beam removal from the foil at turn 2207 with KEK type waveform.**

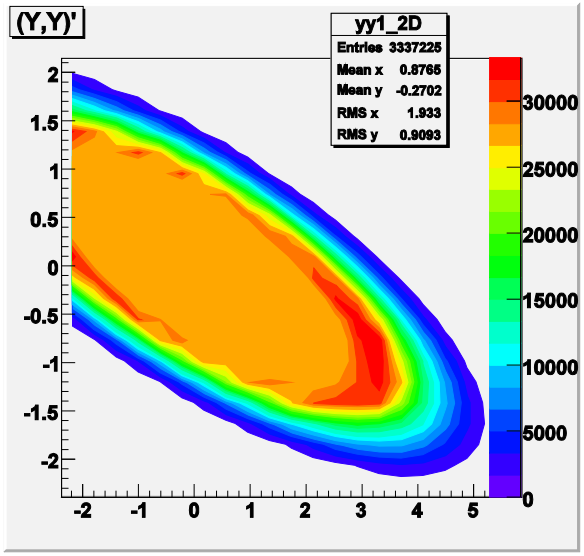


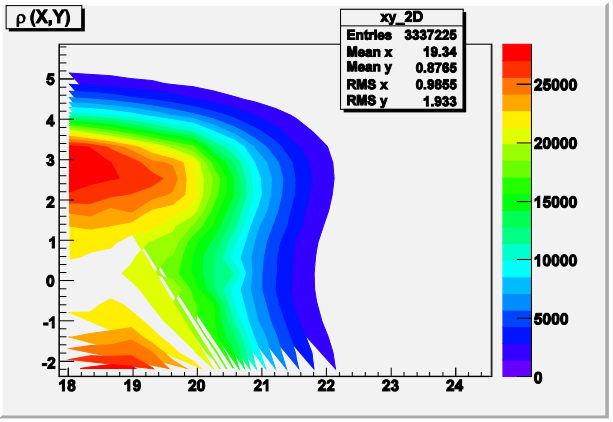



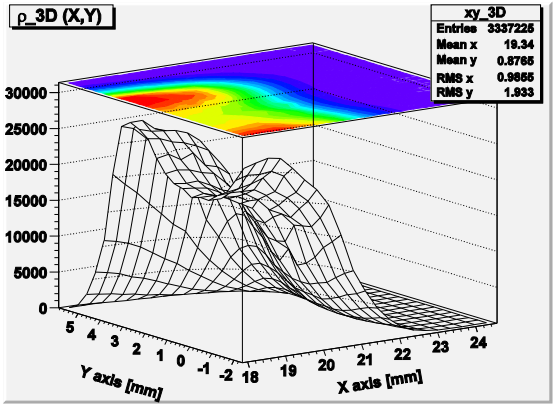




**Particle hit population at foil (top), and horizontal (middle) and vertical (bottom) distributions at turn 2200, with KEK type waveform, for foil half-size of 4.58 X 4.38 mm. The edge of injected beam is located in dX=0.33mm and dY=0.13mm inside from the edge of the foil. Statistics is 8 particles injected at every turn.**

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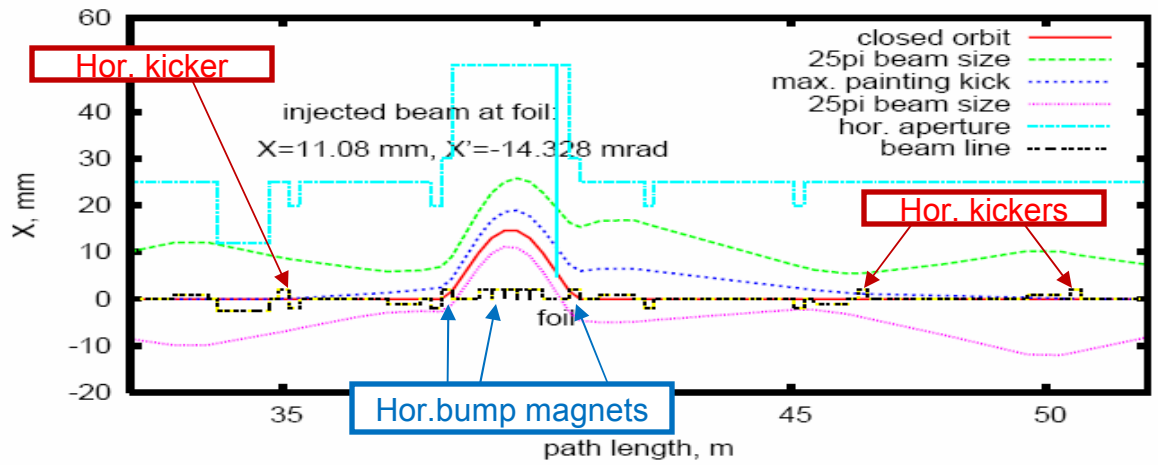
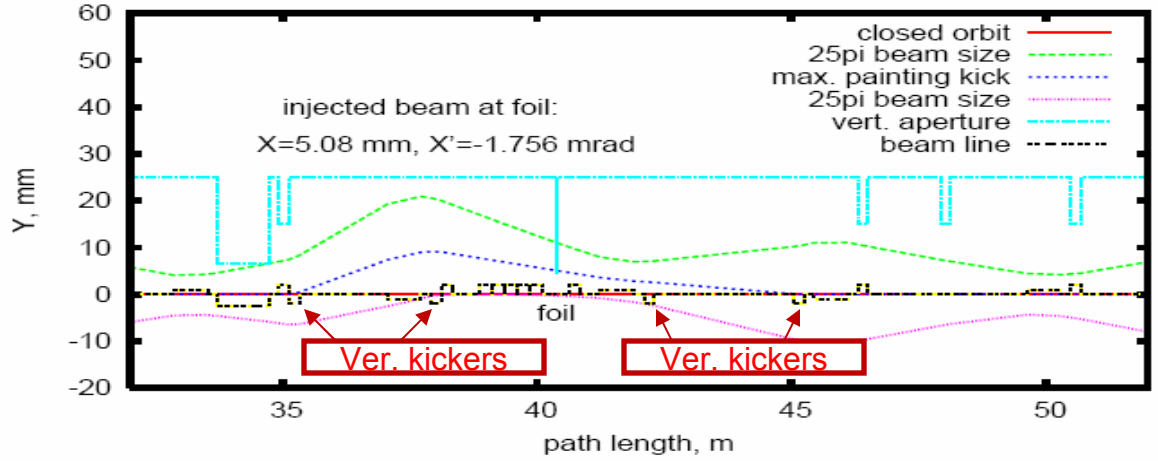
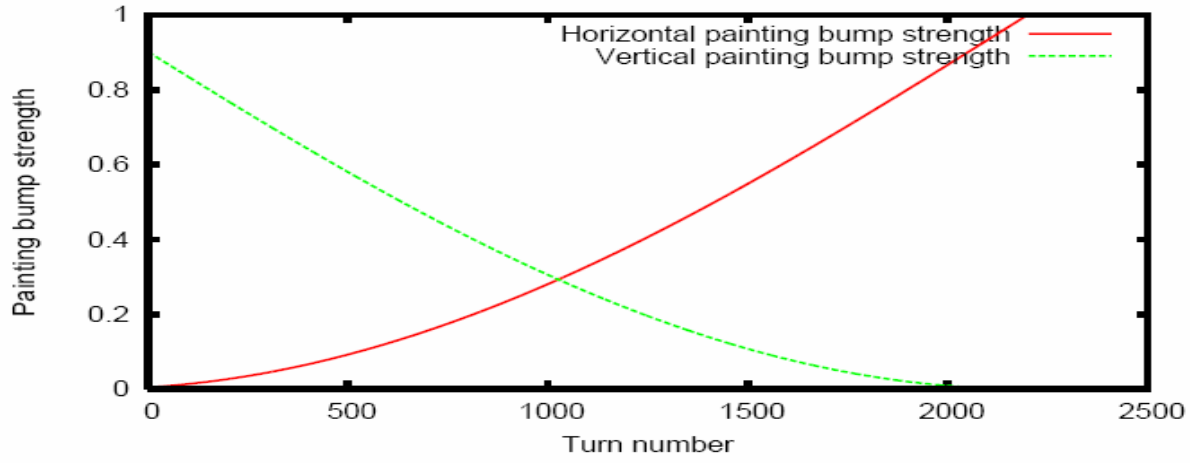
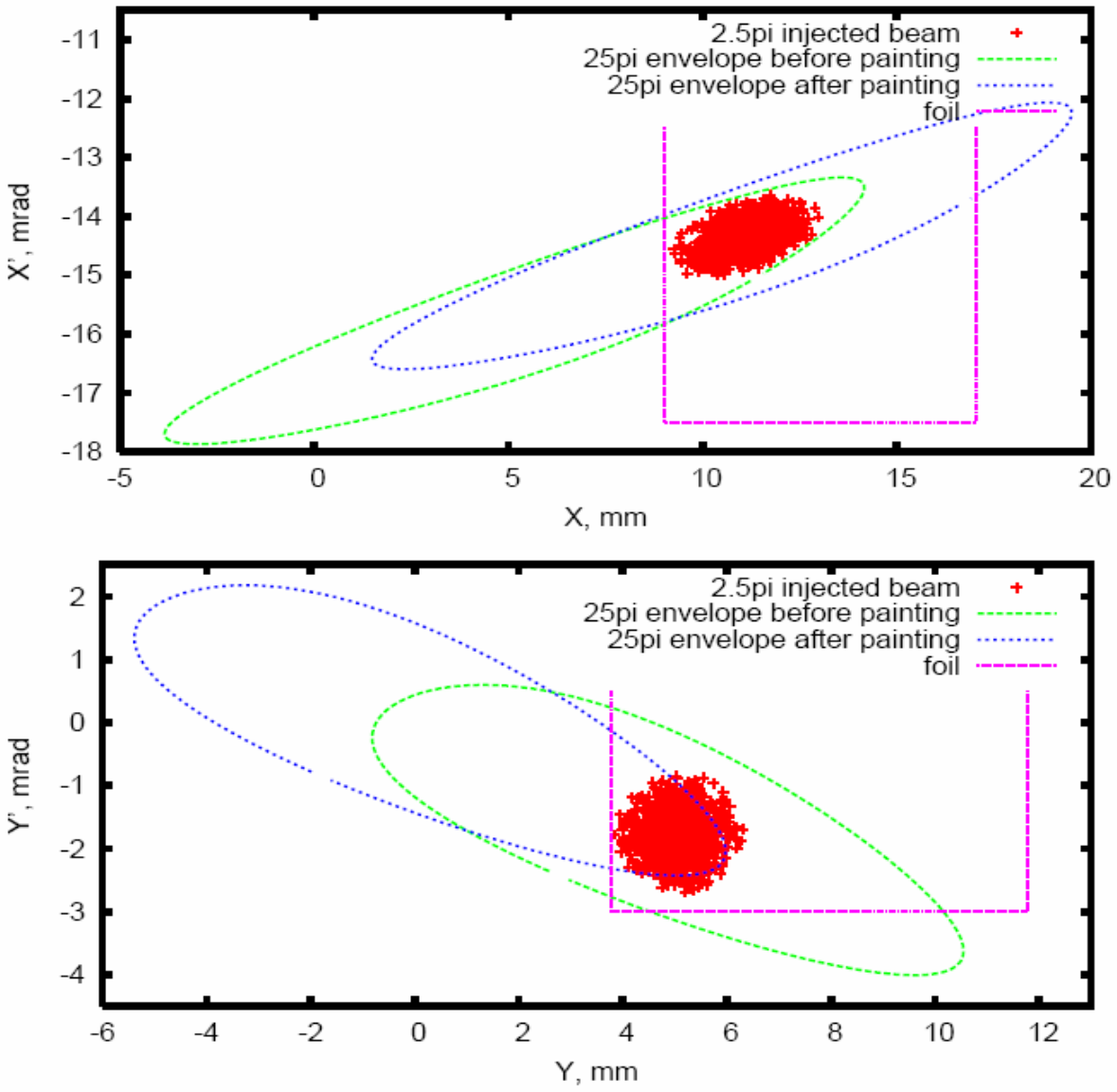


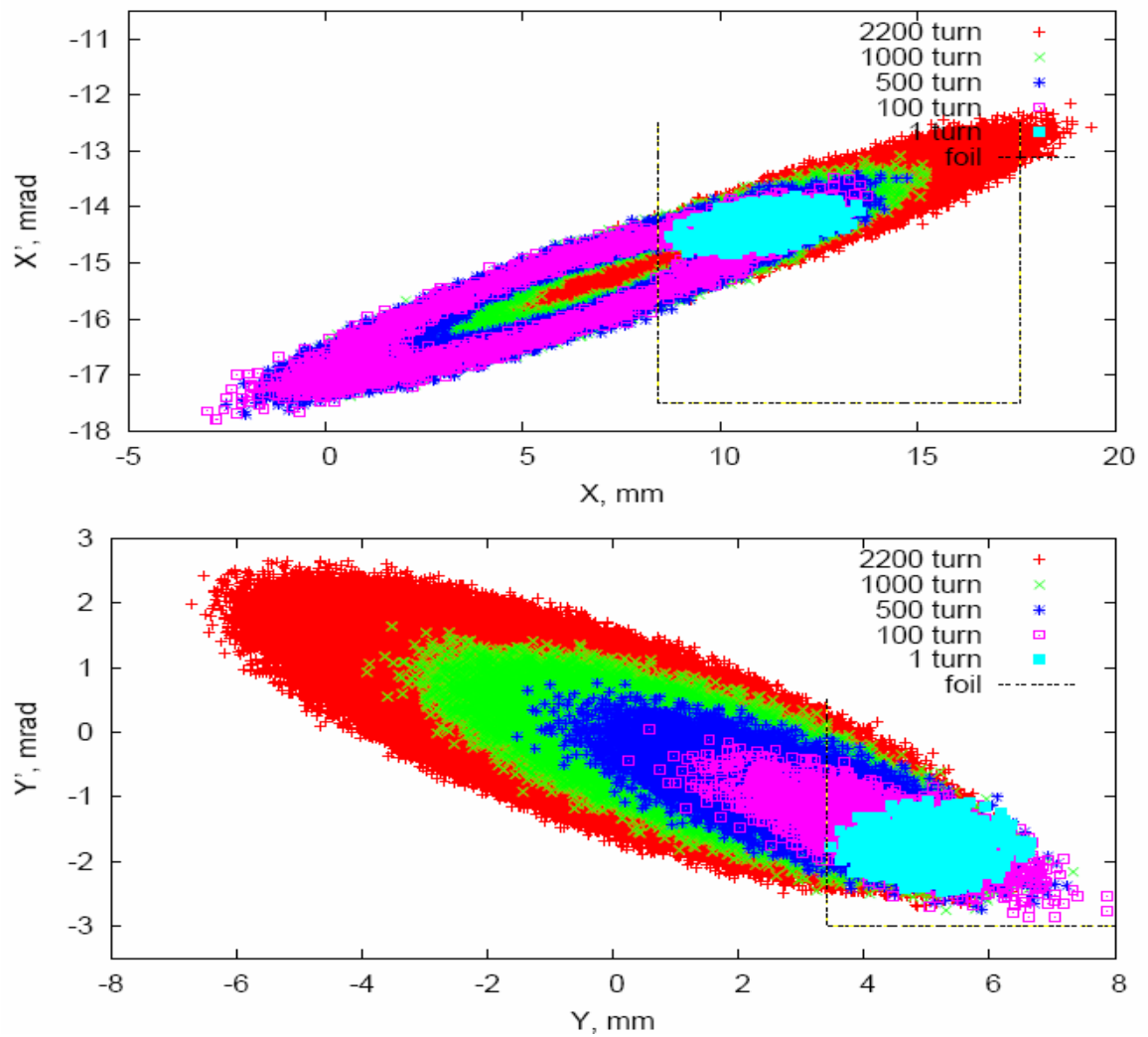



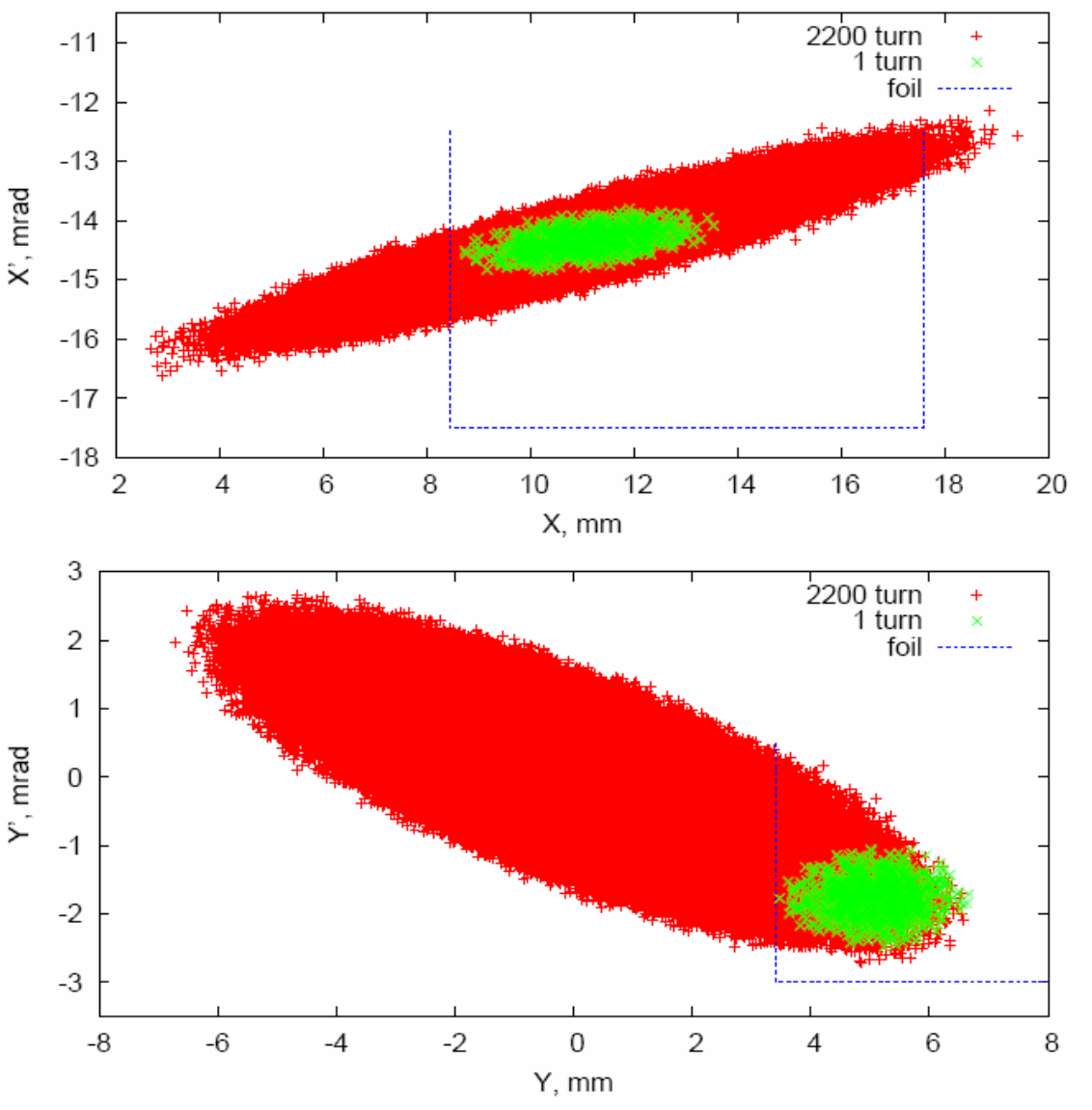

**Horizontal (top) and vertical (middle) beam orbit in the injection section, and painting bump strength (bottom) with COS and SIN waveform.**



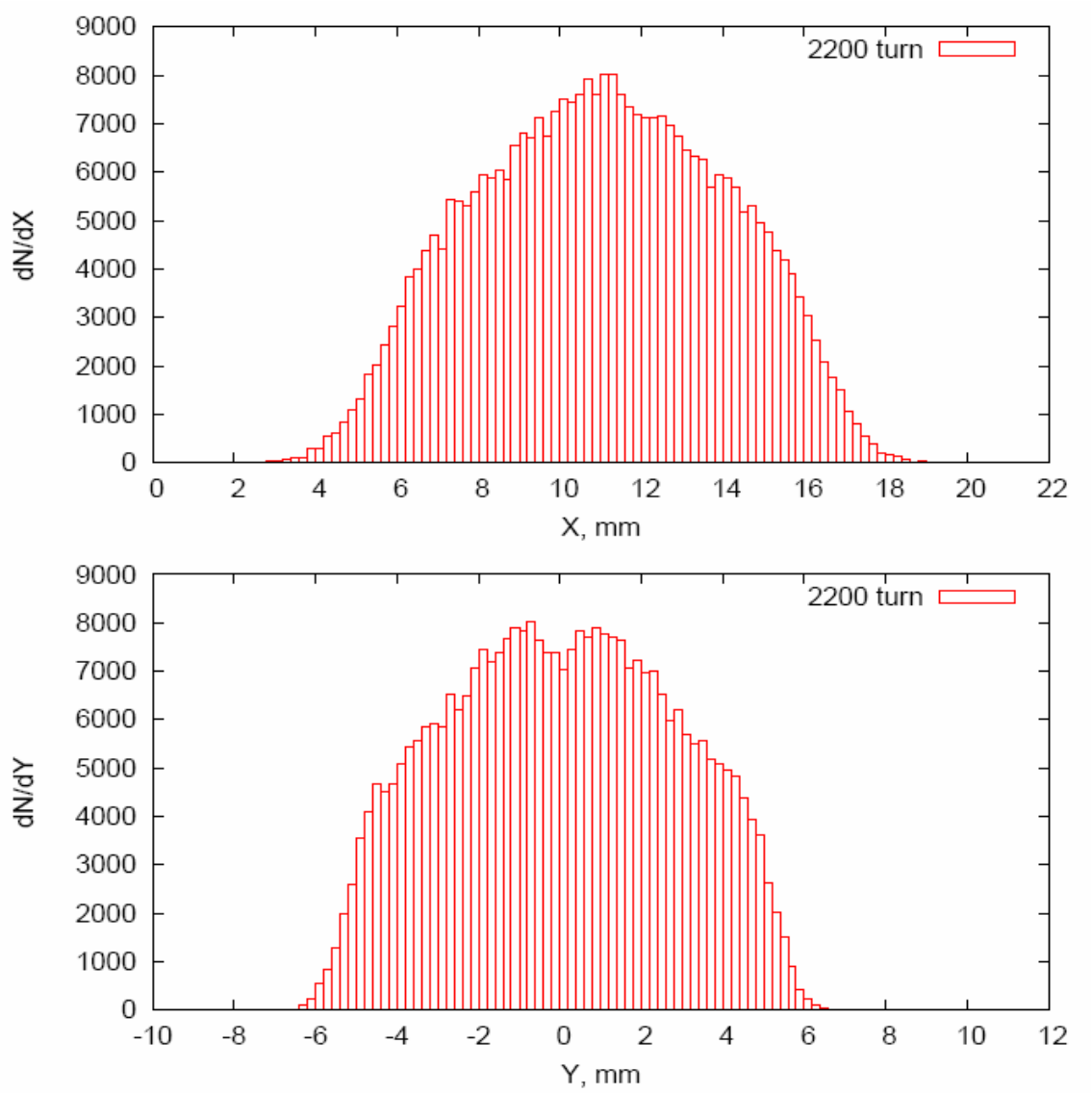

**Horizontal (top) and vertical (bottom) beam position at stripping foil at injection with COS and SIN waveform of painting bump strength.**



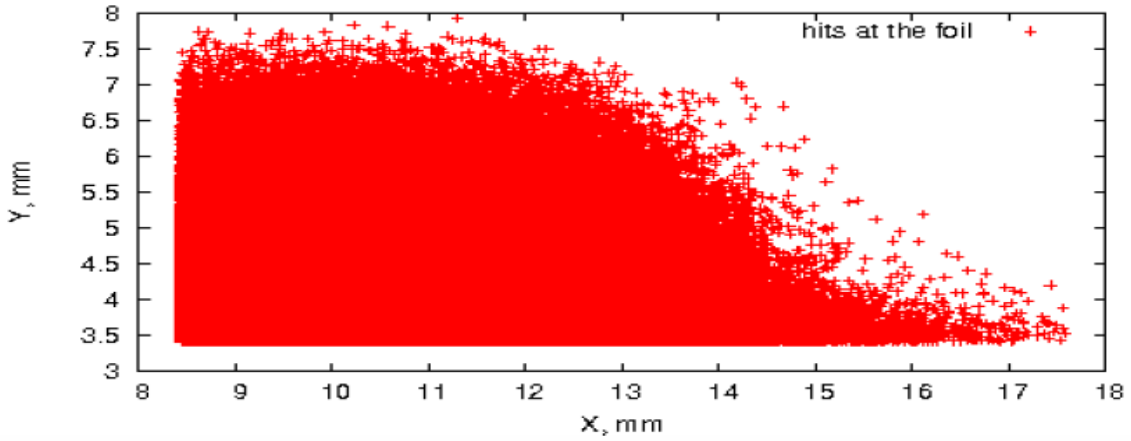

**Horizontal (top) and vertical (bottom) phase plane of circulating beam at turns 1, 100, 500, 1000 and 2200 of injection with COS and SIN waveform of painting bump strength. Average number of each particle interaction with foil is 100.4. Injected beam is taken at 3 σ level: Ax=2.66mm, Ay=1.67mm. Foil half-size is 4.58mm X 4.38mm. Statistics is 30 particles injected at every turn.**

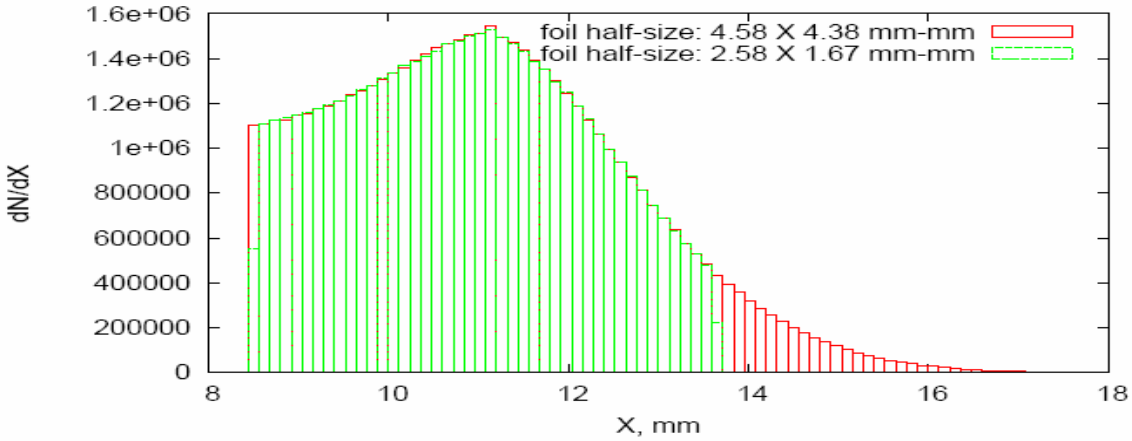


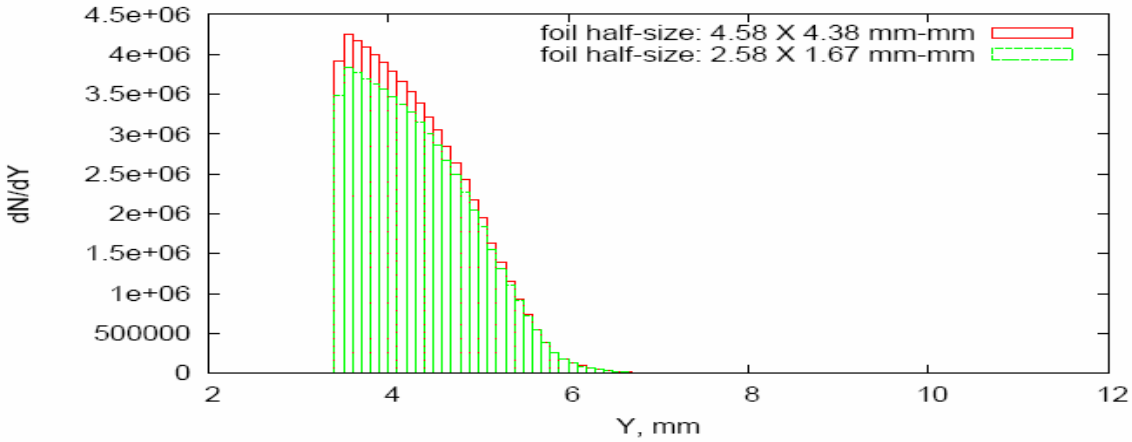

**Horizontal (top) and vertical (bottom) phase plane of circulating beam at turn 2200 of injection with COS and SIN waveform of painting bump strength. Statistics is 30 particles injected at every turn.**



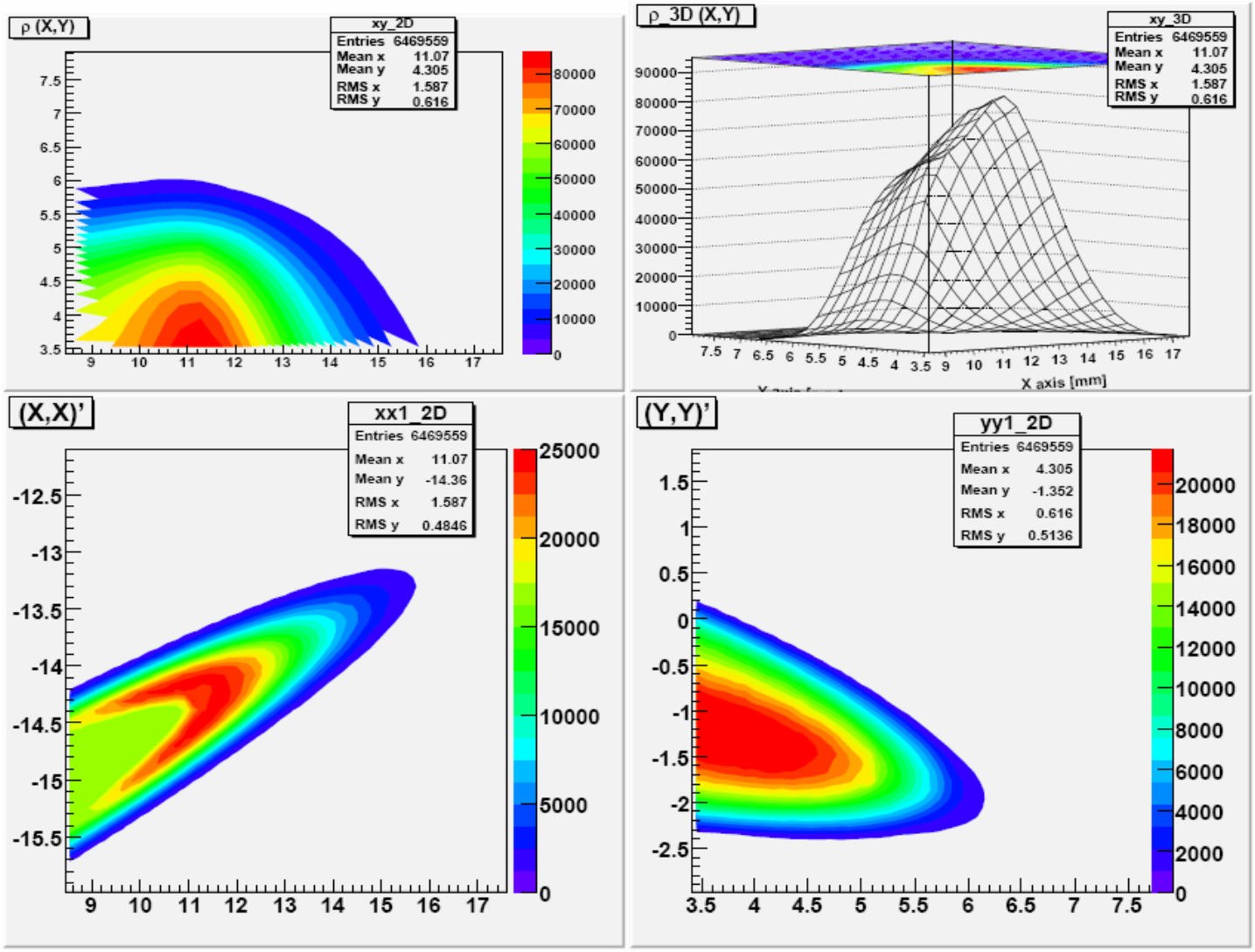

**Horizontal (top) and vertical (bottom) particle distributions after beam removal from the foil at turn 2207 with COS and SIN waveform of painting bump strength.**



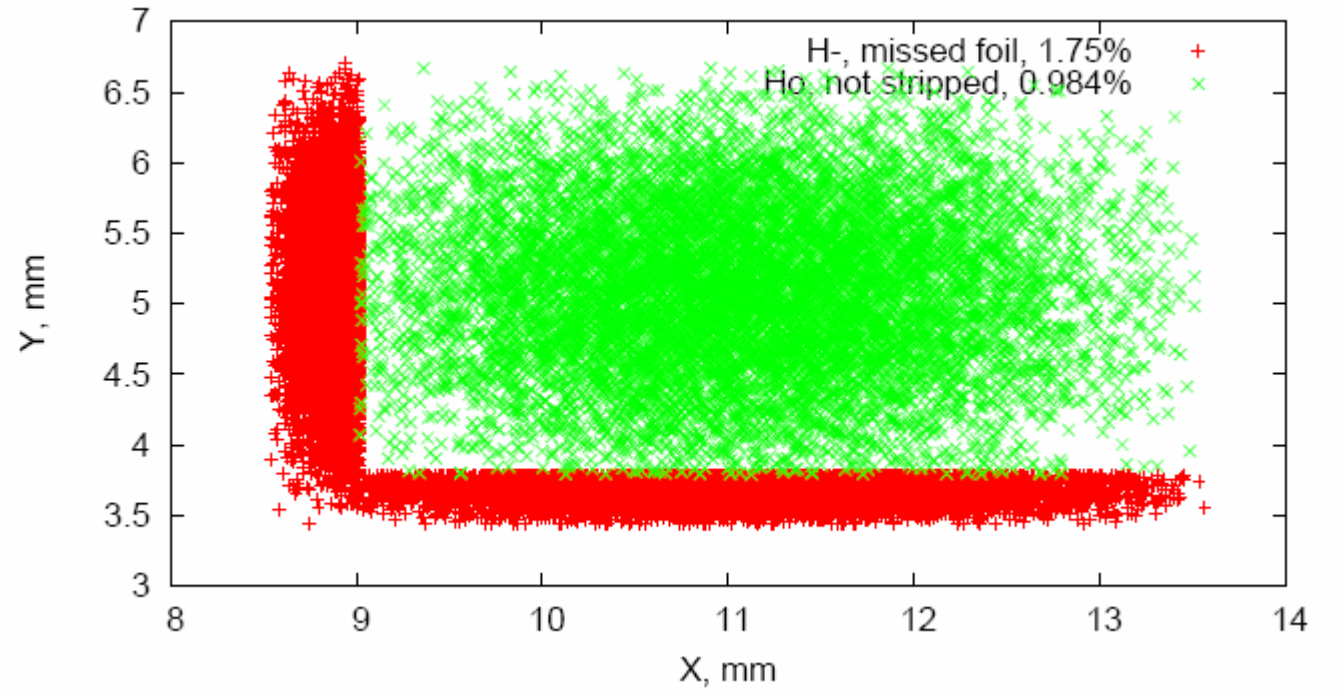



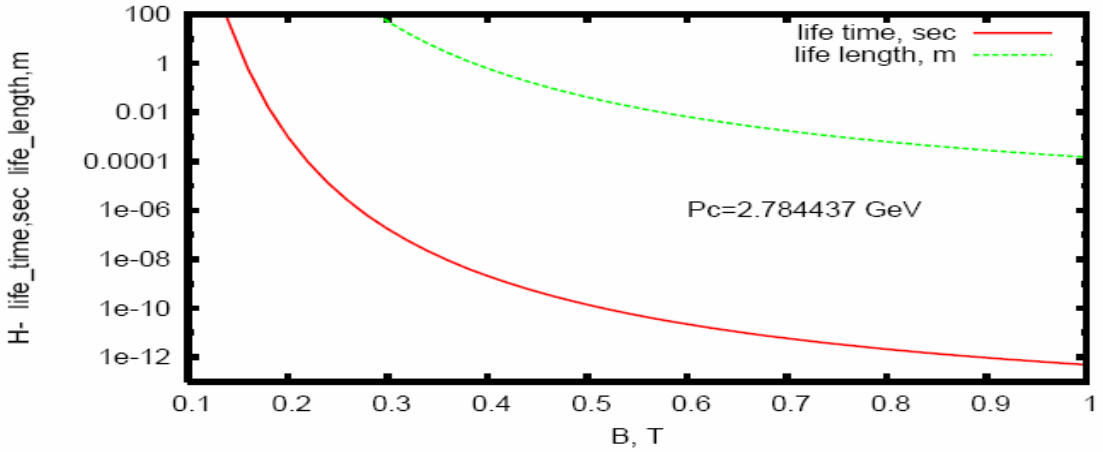

**Particle hit population at foil (top), and horizontal (middle) and vertical (bottom) distributions at turn 2200 with COS and SIN waveform of painting bump, for foil half-size of 4.58 X 4.38 mm-mm, and foil with size equal to size of injected beam (half-size of 2.58 X 1.67 mm-mm). In both cases injected beam is located at the edge of the foil. This shows that density of particle hits in the maximum of distribution almost does not depend on the foil size. Statistics is 30 particles injected at every turn.**

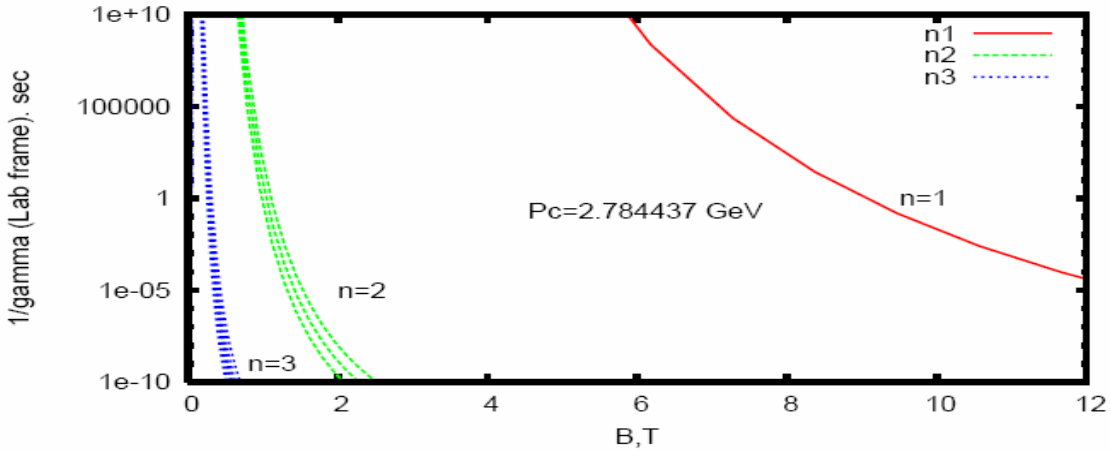


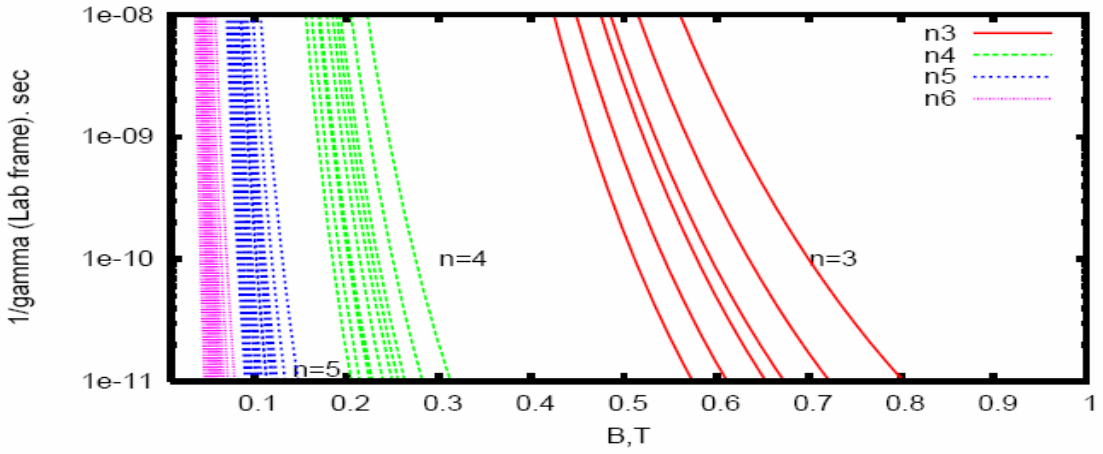

**Particle hit population (top), and horizontal and vertical phase distributions (bottom) at the foil with COS and SIN waveform of painting bump strength. Hit density in a maximum of distribution is 776700 hits/mm$^2$.**




**Ho atoms population at the foil and H- missed the foil in a case of injected beam center location in 2.32 $\sigma_{x,y}$ distance from the foil corner with COS and SIN waveform of painting bump strength. Foil half-size is 4mm X 4mm.**




**Lifetime of H- ions in a magnetic field (top). Calculated lifetime of excited states hydrogen Ho atoms in magnetic field of bump magnet for Pc=2.784437 GeV (middle and bottom).**

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| normalized acceptance | 40 π $mm \cdot mrad$ |
| normalized emittance of the beam after painting, $\varepsilon_{total}$ | 25 π $mm \cdot mrad$ |
| Geometric emittance after painting | |
| $\varepsilon_{total} = 25\ \pi \times (0.938272/2.784437)$ | 8.4243 π $mm \cdot mrad$ |
| Momentum spread after painting, $dP/P$ at 3σ level | $1 \times 10^{-3}$ |
| Beta functions in the injection beam line at the foil, $\beta_x, \beta_y$ | 5.28 $m$, 2.21 $m$ |
| Injected beam half-size, $3\sigma_x = 3 \times sqrt(5.28 \times 0.1404)$ | 2.58 $mm$ |
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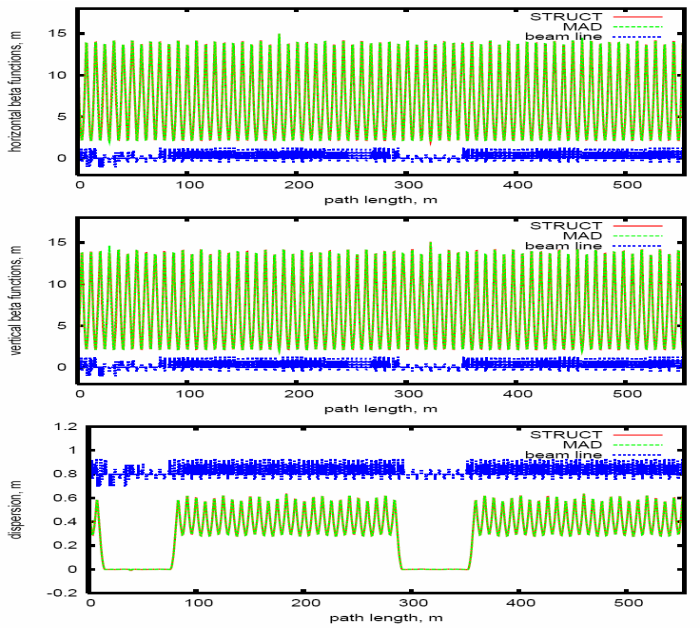




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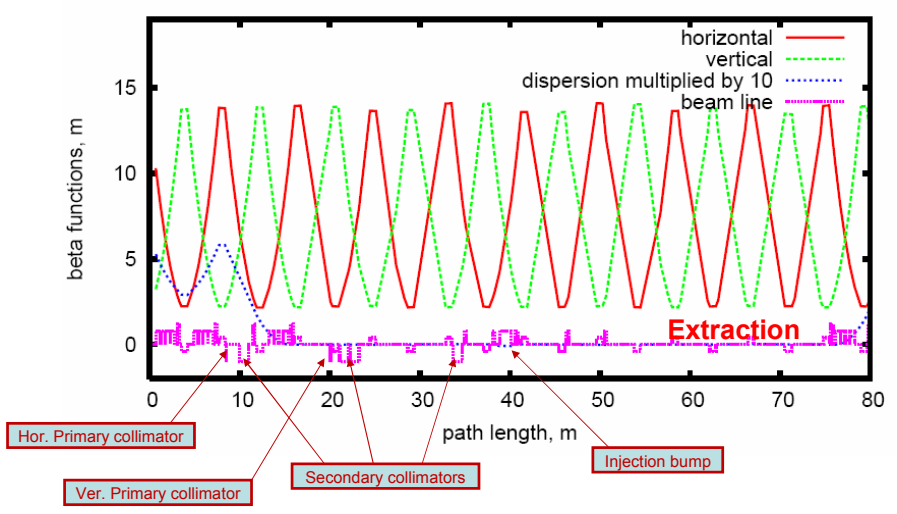


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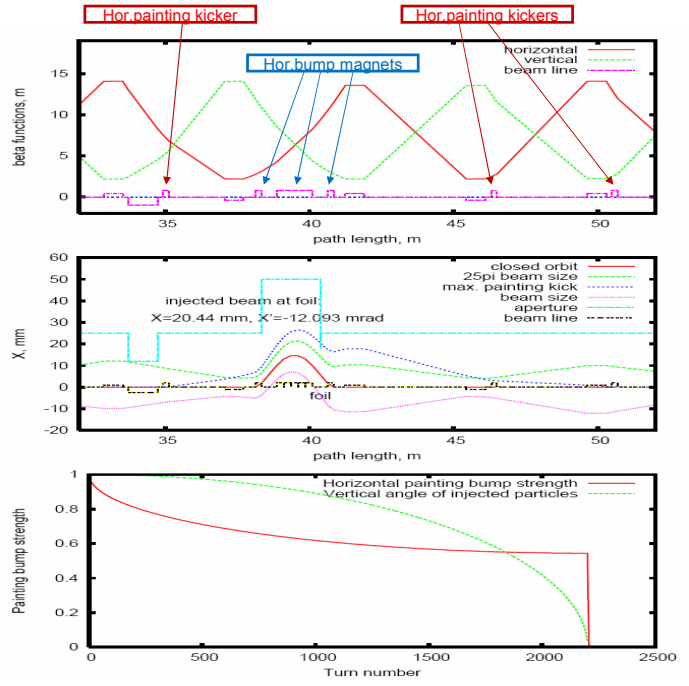


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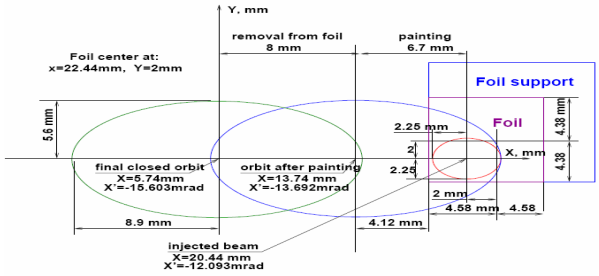
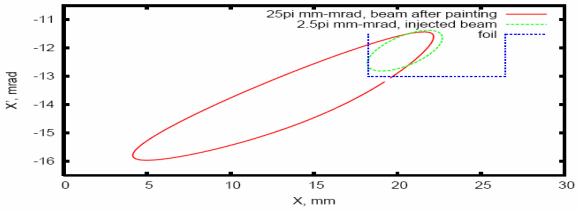
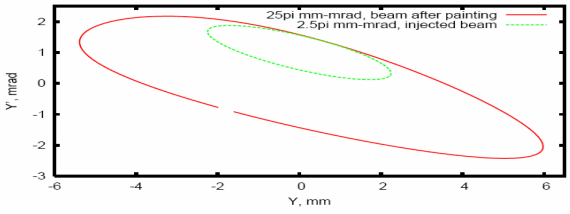
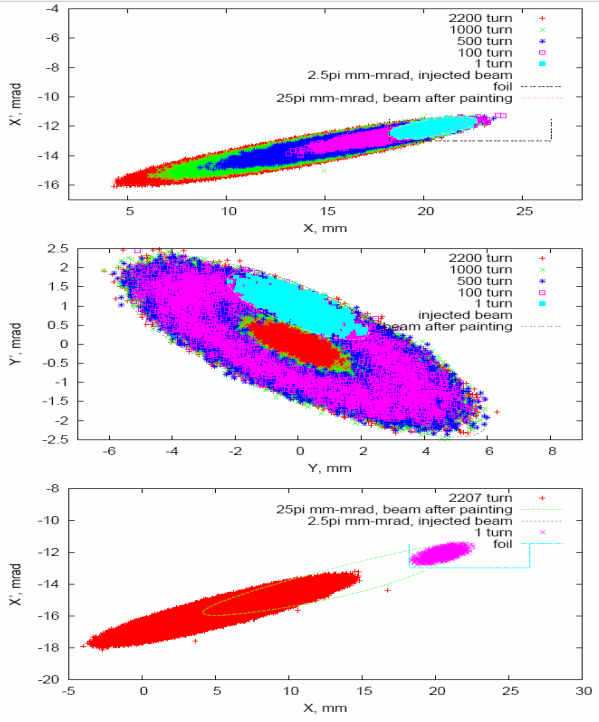



**Beam position at stripping foil at painting injection with KEK type waveform.**

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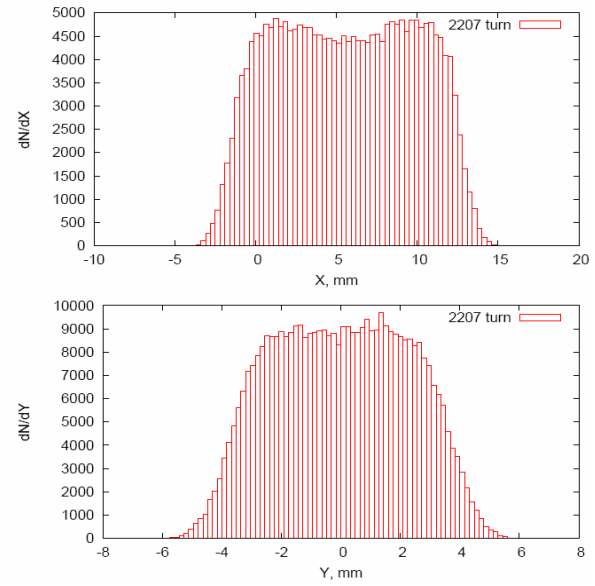
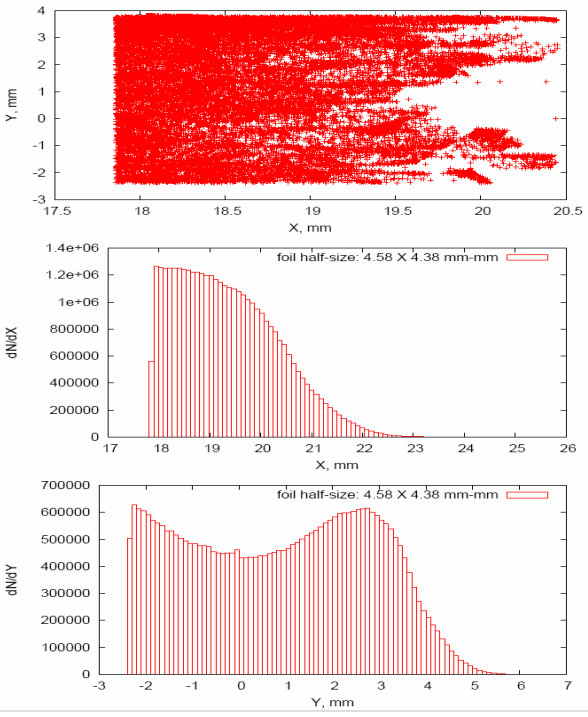
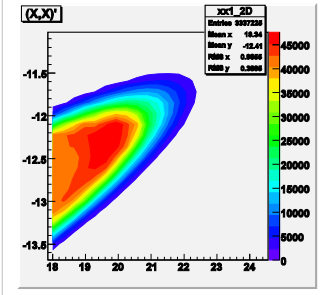
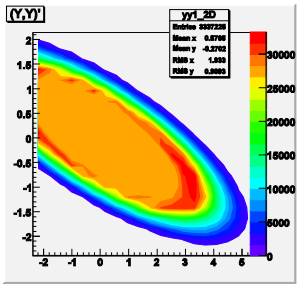


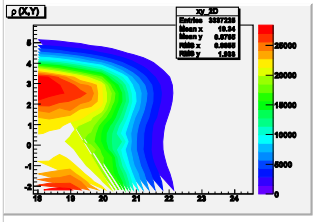

**Horizontal (top) and vertical (bottom) particle distributions after beam removal from the foil at turn 2207 with KEK type waveform.**

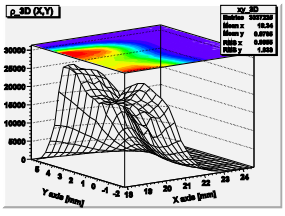



**Particle hit population at foil (top), and horizontal (middle) and vertical (bottom) distributions at turn 2200, with KEK type waveform, for foil half-size of 4.58 X 4.38 mm. The edge of injected beam is located in dX=0.33mm and dY=0.13mm inside from the edge of the foil. Statistics is 8 particles injected at every turn.**

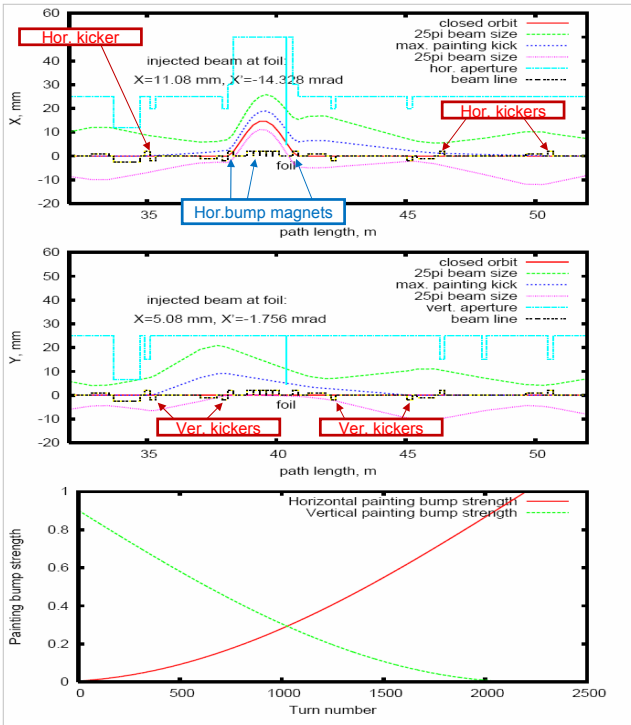


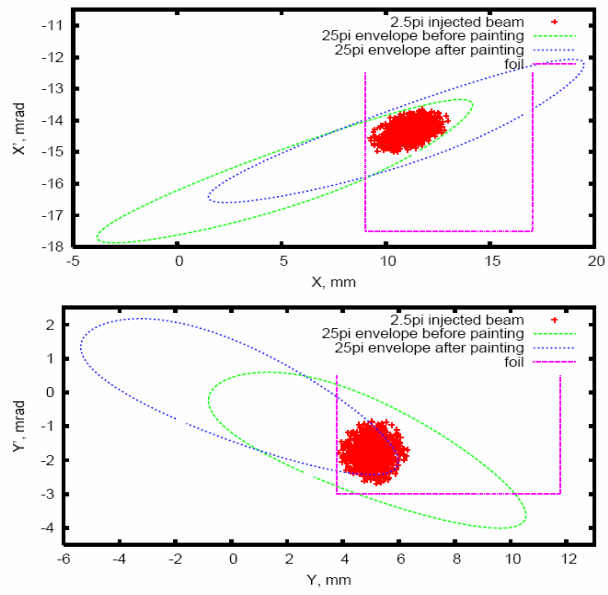



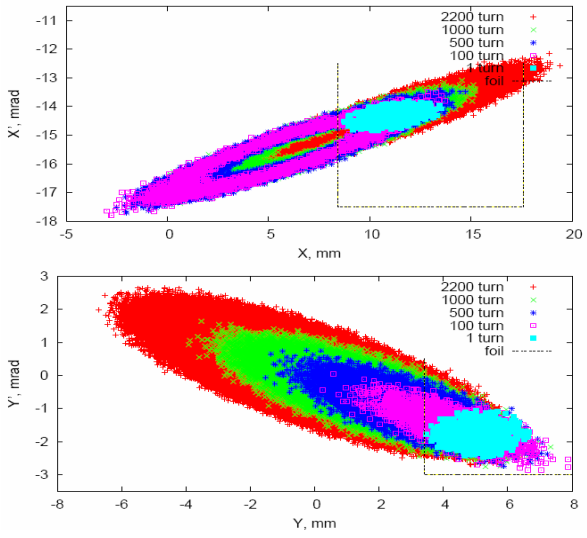

**Particle hit population at foil (top), and horizontal (middle) and vertical (bottom) distributions at turn 2200, with KEK type waveform, for foil half-size of 4.58 X 4.38 mm. The edge of injected beam is located in dX=0.33mm and dY=0.13mm inside from the edge of the foil. Statistics is 8 particles injected at every turn.**



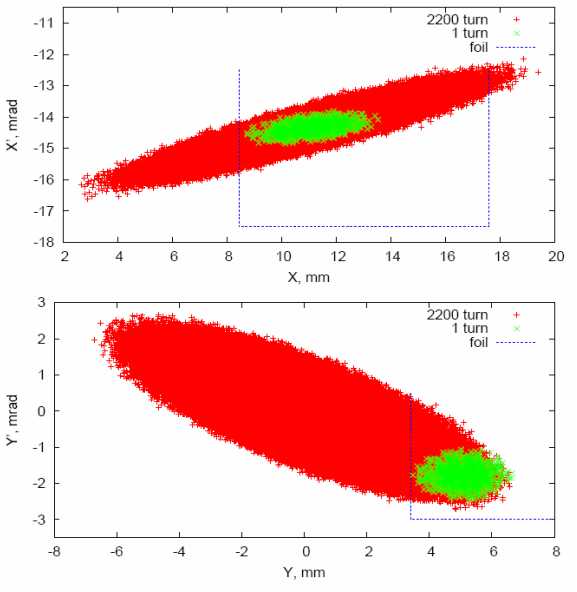

**Horizontal (top) and vertical (middle) beam orbit in the injection section, and painting bump strength (bottom) with COS and SIN waveform.**



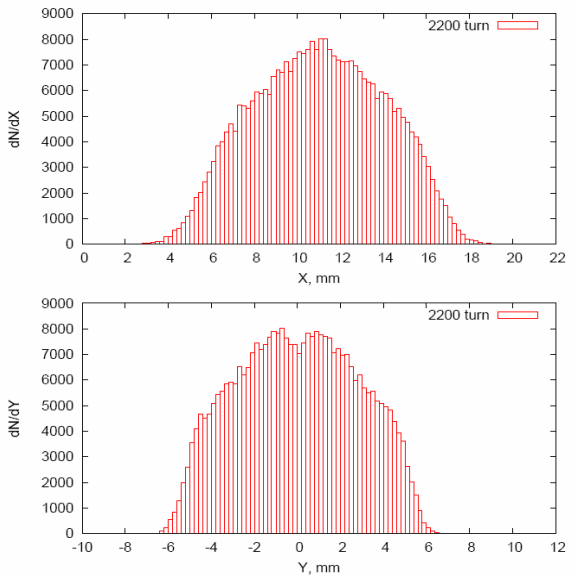

**Horizontal (top) and vertical (bottom) beam position at stripping foil at injection with COS and SIN waveform of painting bump strength.**



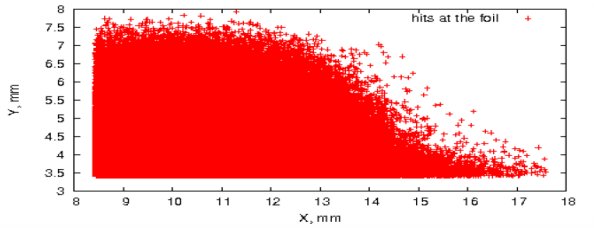

**Horizontal (top) and vertical (bottom) phase plane of circulating beam at turns 1, 100, 500, 1000 and 2200 of injection with COS and SIN waveform of painting bump strength. Average number of each particle interaction with foil is 100.4. Injected beam is taken at 3 σ level: Ax=2.66mm, Ay=1.67mm. Foil half-size is 4.58mm X 4.38mm. Statistics is 30 particles injected at every turn.**

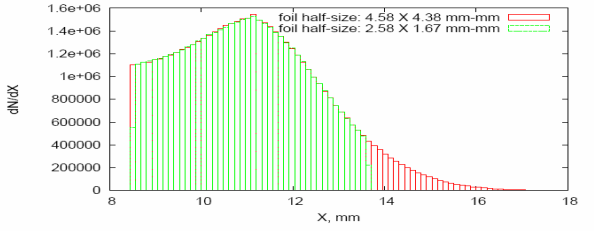


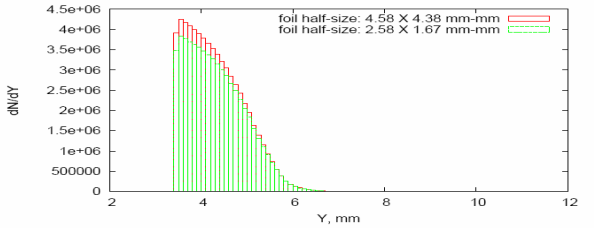

**Horizontal (top) and vertical (bottom) phase plane of circulating beam at turn 2200 of injection with COS and SIN waveform of painting bump strength. Statistics is 30 particles injected at every turn.**



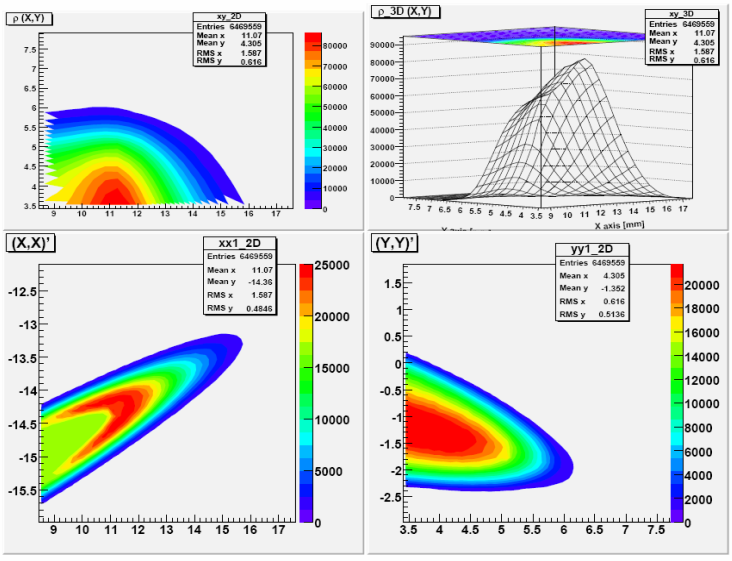

**Horizontal (top) and vertical (bottom) particle distributions after beam removal from the foil at turn 2207 with COS and SIN waveform of painting bump strength.**



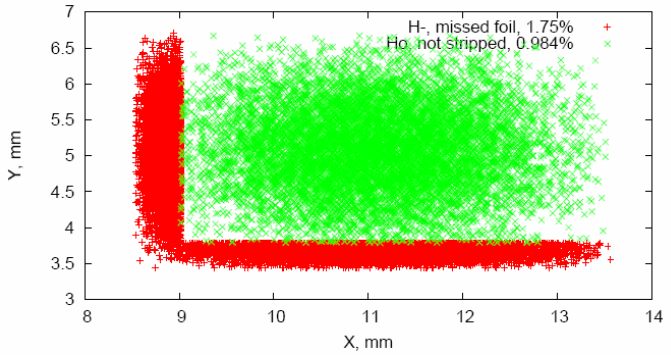



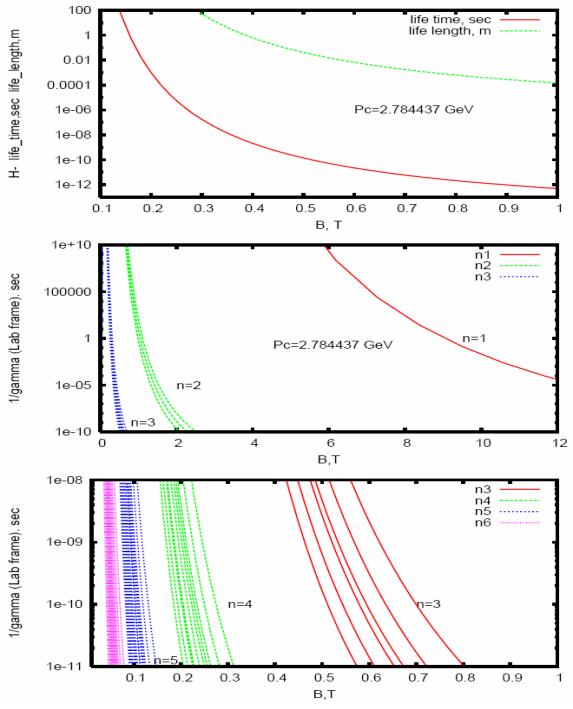

**Particle hit population at foil (top), and horizontal (middle) and vertical (bottom) distributions at turn 2200 with COS and SIN waveform of painting bump, for foil half-size of 4.58 X 4.38 mm-mm, and foil with size equal to size of injected beam (half-size of 2.58 X 1.67 mm-mm). In both cases injected beam is located at the edge of the foil. This shows that density of particle hits in the maximum of distribution almost does not depend on the foil size. Statistics is 30 particles injected at every turn.**




**Particle hit population (top), and horizontal and vertical phase distributions (bottom) at the foil with COS and SIN waveform of painting bump strength 1.7. Hit density in a maximum of distribution is 776700 hits/mm$^2$.**




**Ho atoms population at the foil and H- missed the foil in a case of injected beam center location in 2.32 $\sigma_{x,y}$ distance from the foil corner with COS and SIN waveform of painting bump strength. Foil half-size is 4mm X 4mm.**




**Lifetime of H- ions in a magnetic field (top). Calculated lifetime of excited states hydrogen Ho atoms in magnetic field of bump magnet for Pc=2.784437 GeV (middle and bottom).**